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## **MARUTI at ARDEC Final Report**

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## **Introduction**

This is the final report of the effort undertaken at the University of Maryland, sponsored by DARPA under the DSSA (Domain Specific Software Architectures) program. The activities reported here required an active cooperation and collaboration of US Army ARDEC (Automation and Robotics Laboratory) and the University of Maryland (Computer Science Department). The principal investigators have been developing a hard real-time operating system, MARUTI, at the University of Maryland. The goal of this effort was to demonstrate the applicability and usefulness of this operating system for exercising PID control at high frequency on the ATB1000 testbed which has been used to simulate a gun turret. A MARUTI based PID controller which operates at 200 Hz and 400 Hz was successfully implemented to demonstrate this feasibility.

## **The MARUTI Project**

The goal of the MARUTI project is to create an environment for the development and deployment of applications with hard real-time, fault tolerance, as well as security requirements. Such applications must be able to execute on a distributed, heterogeneous hardware base. A framework for such an environment has been created and the feasibility of the design have been demonstrated through initial implementations of the prototype components of the MARUTI environments. The development of a comprehensive environment capable of meeting the hard real-time, fault tolerance and security requirements of applications necessitates the use of new and innovative techniques for all parts of the system. Our approach continues to be that of a balance effort on both theoretical studies and prototype implementations with a continual feedback from one to the other.

The current version of MARUTI has been implemented to run in a single machine or in a multiple machine environment of PC Compatible (486) machines. Some of the tools implemented to date to support application programming include a precompiler for MPL (MARUTI Programming Language) and a processor for MCL (MARUTI Configuration Language). In addition, some scheduling analysis tools have been implemented and are ported to a 486 based platform. Detailed information about the MARUTI can be obtained from <http://www.cs.umd.edu/projects/MARUTI>.

## **The ATB1000 Testbed**

The ATB1000 has been designed to assist in the development of advanced controllers for pointing turreted weapon systems accurately in harsh environments where there are many nonlinearities that degrade performance. It is an experimental fixture used for the design testing and validation of advanced control laws, as well as a test fixture for modeling turreted weapon systems to develop controllers for weapon systems without having to use the costly weapon systems themselves. The ATB1000 testbed allows the flexibility to test advanced control algorithms in a controlled test environment. A controlled performance can be tested by varying on-line nonlinearities such as backlash and friction. Once the controller passed testing on the ATB1000 testbed, it could then be tested on the actual gun systems. It was designed with nonlinearities that could be varied on-line, including two major nonlinearities: backlash and friction.

The ATB1000 was designed to simulate the types of nonlinearities and disturbances that are present in typical flexible beam stabilization problems encountered in physical systems such as a gun turret. The fixture's main body is an aluminum disc free to rotate in the horizontal plane. Affixed to the edge of the disc is an interchangeable steel rod (barrel), 1 meter in length. The control objective is to minimize the error between the commanded barrel tip position and the actual tip position.

The actuator used to control the angular motion of the disc is a brushless DC motor which transmits its torque through an on-line variable backlash mechanism and an off-line variable compliance. A mechanism is also used to introduce on-line variable friction by applying a force to the edge of the disc.

Two types of disturbances are introduced into the system. The first can be described as base motion disturbances. The base motion introduces x-y motion and rotation in the horizontal plane using four motor driven slides connected to the base through two bearings. The second disturbance attempts to simulate the effects of periodic impulsive disturbances on the system through the use of a vibrating solenoid mounted on the disc.

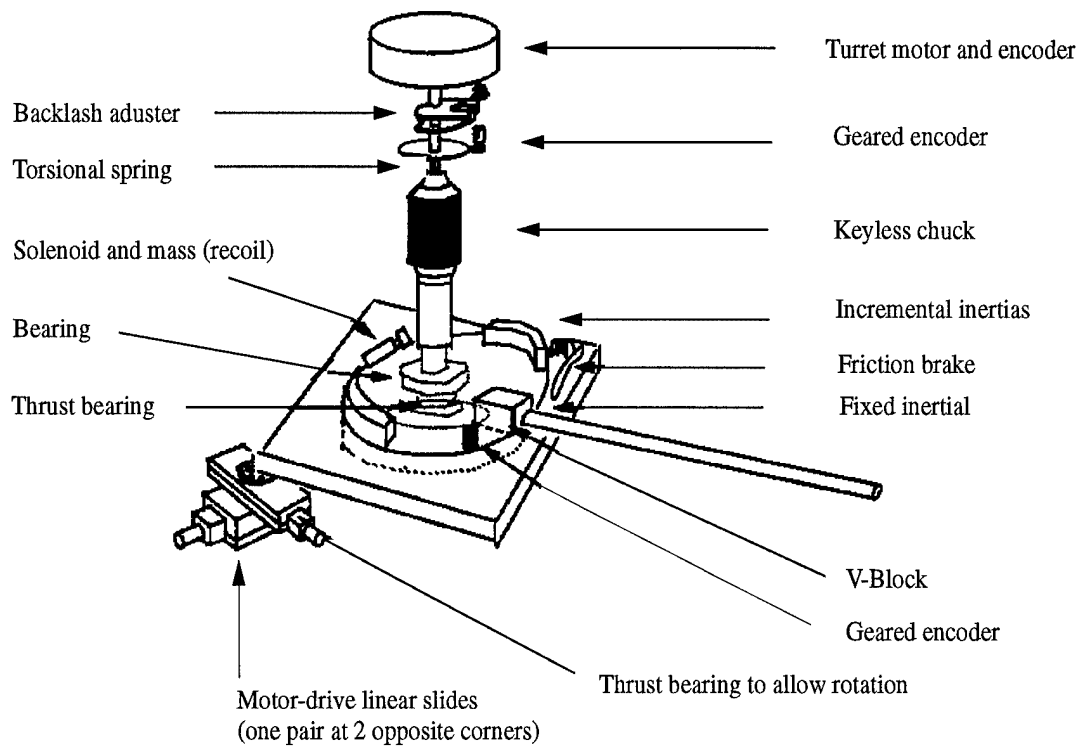
The beam tip position is measured using a laser-based system which is mounted on an arm which rotates in the horizontal plane. The beam tip has a flat mirror attached to it while the laser emitter and detector are attached to the arm. During experiments, that laser arm keeps the beam focused on the beam tip.

The testbed has been interfaced to a wide variety of digital controllers including the MatrixX AC100, Matlab/Dspace, and NI's LabView, and now the MARUTI operating system. The testbed was designed to include many sensors for verification of controllers as well as providing sensor inputs to adaptive controllers. The testbed has a movable base capable of 3 degree of planar motion for simulating base motion disturbances such as in helicopters, tanks, etc. Sensors include a laser tip position measuring system, accelerometers on the base itself, encoders at the control motor, after the backlash adjuster, and at the base of the inertia wheel. The beam, attached to the inertia wheel has two strain gauges mounted along the beam at 1/3 and 2/3 respectively, as well as an accelerometer and mirror at the tip. The mirror used in conjunction with the laser can supply very accurate tip position information. It should be noted that the sensors at the tip were set up for controller performance validation and model creation. Due to the harsh environment at the tip of a gun system and the high cost of specialized tip sensors it is not feasible to have such sensors available on actual gun systems.

There are two ways in which you can receive output/information from the ATB1000, one method is analog output and the other is encoder output/information. The analog output can consist of the following: quadcell position, quadcell sum, base accelerometer 1, base accelerometer 2, strain gage one, strain gage two, turret motor velocity, beam tip accelerometer, and base accelerometer 3. The encoder output can consist of the following: slide motor 1, slide motor 2, slide motor 3, slide motor 4, turret motor, backlash, laser arm, and I wheel. The analog inputs to the ATB1000 are: firing solenoid, laser arm motor, backlash setting, and friction setting.

A Schematic drawing of the ATB1000 is included on the following page (see Figure 1).

## ATB1000 Testbed Structure



**Figure 1.**

## **PID Controller**

The first PID controller consists of only the following data transfer: the encoder output is the I-Wheel and the analog input is the turret motor. Although the controller is a very simple one, the purpose of this experiment was to develop device drivers to interface with the ATB1000, develop a PID controller, interface graphics, and to validate the fact that the MARUTI operating system could be utilized to support systems that required hard real-time constraints during execution. The PID controller operates at 400 Hz and the graphics display currently operates at 50 Hz.

## **MARUTI Environment**

Two MARUTI environments were used in this experiment: (1) development environment (2) run-time environment. The development environment ran under Berkeley Unix. It is in this environment that one needs to code in GNU C to the device drivers. In this particular case we developed device drivers for encoder boards, A/D boards, and D/A boards. We also developed in GNU C a PID controller for the I-Wheel testbed. During the developmental phase the rate at which the processes are to run is needed. The entire system (PID controller, device drivers, graphics libraries, process rates, & MARUTI libraries) was linked together so that it could be downloaded to the run-time environment. All of this was done by the system, the user merely types "mpc filename" (MARUTI Program Compile) at the command line.. The user rebooted the system under the MARUTI run-time environment and the system displayed graphical results as the system ran and tried to control the I-Wheel. Figure 2 contains the software/hardware diagram for the testbed environment, entitled "ARDEC/MARUTI Testbed Implementation". The entire hardware development system consisted of a 486 PC, an encoder board, and an A/D D/A board.

## ARDEC/Maruti Testbed Implementation

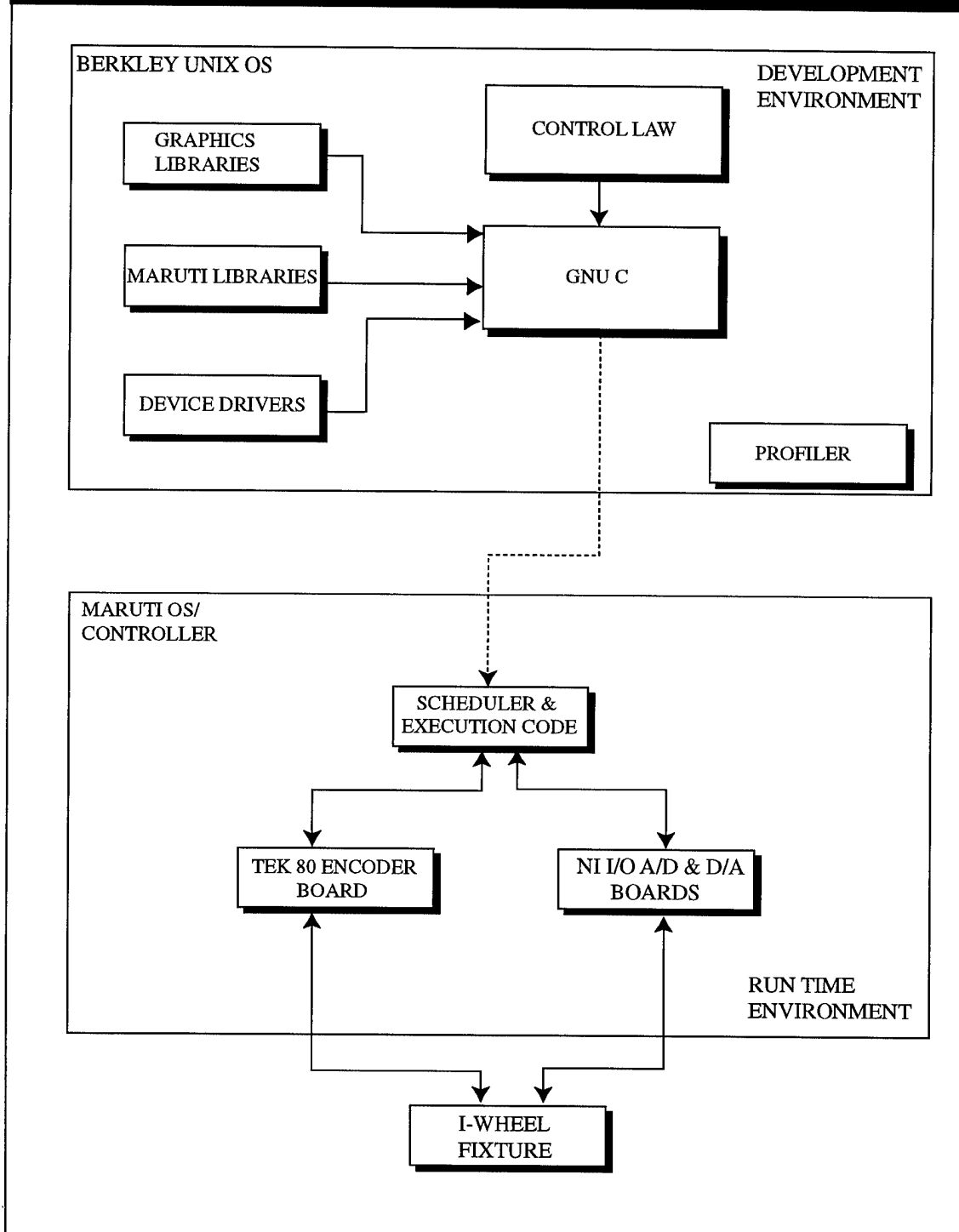


Figure 2.

## **ARDEC/MARUTI Controller Architecture**

The ARDEC/MARUTI controller was developed using the "ArTek" Architecture Description Language (ADL), jointly developed by ARDEC, Automation and Robotics Lab, and Teknowledge Corporation under the ARPA "Domain Specific Software Architectures (DSSA)" program. A formal architecture description language (ADL) "schema" for describing architectures has been developed. The schema is part of a developing methodology and infrastructure for support tools to help specify, design, and validate embedded vehicle management and decision support architectures. The schema is currently in version 3.0 release and is being applied to several application programs related to embedded crew decision aids and control systems in order to test concepts methodology and tools to generate feedback from software developers. The formal language is laid out as a number of description records, each with its specific set of fields. The ADL standardizes component (defined as first class objects) interfaces which define the infrastructure for the architecture and the rescue requirements for these interconnections. The MARUTI/ARDEC PID Controller is composed of three main components: PID, Graphics, and I-Wheel. Graphically, the components are represented as ellipses, the input ports are represented as outward point on the right side of the rectangle, and output ports are represented as inward point on the left side of the rectangles. Components/elements are the basic entity within an architecture. One way to think of an architecture element is that it is a functional entity that transforms input data into output data. The connections define the topology of the architecture by defining which elements communicate with which others. When looking at the inside of the element, ports specify how the connection in the larger context relates to the implementation of the element. An example of graphical output using the ArTek architecture description language are presented in Figures 3 through 6.

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MARUTI - ARDEC PID CONTROLLER

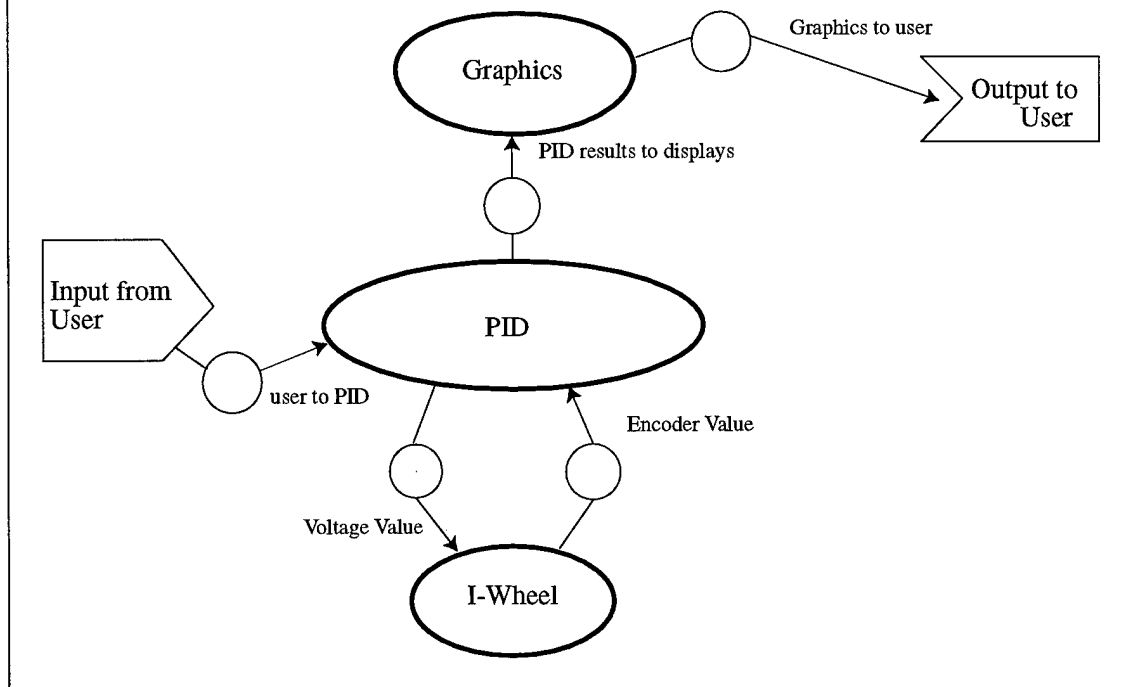


Figure 3.

Element -- DC Monitor 'PID'

PID & INPUT-OUTPUT

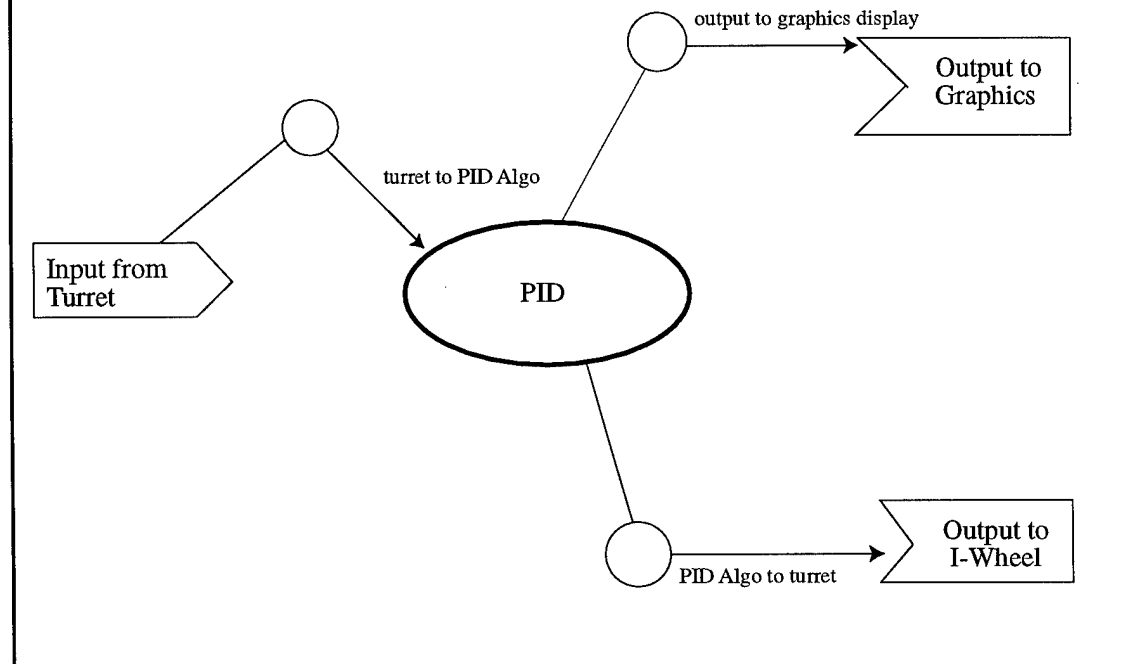
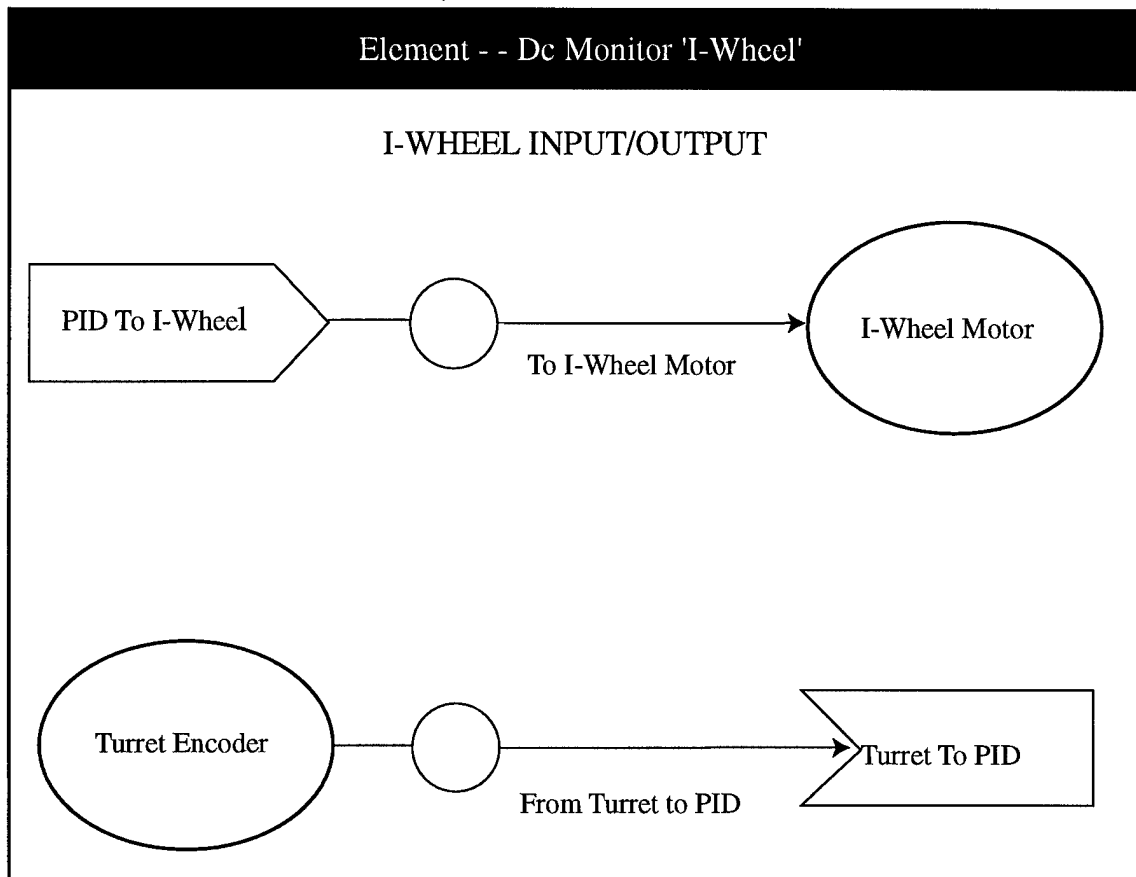
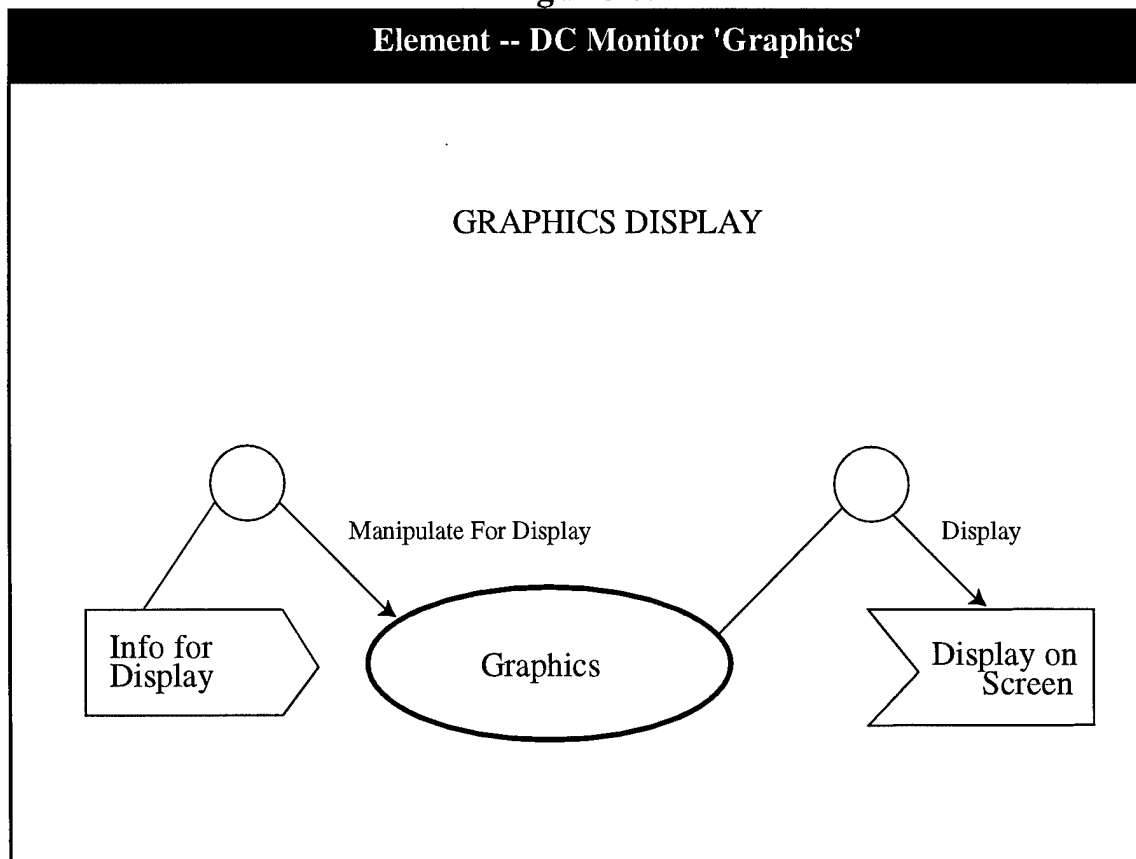


Figure 4.



**Figure 5.**



**Figure 6.**

## **Results**

The PID controller implemented using MARUTI accepted the position and velocity as inputs and produced the motor current level as the output. It was successfully demonstrated to operate at 400 Hz. It was also successfully tested to operate at 1000 Hz when the machine used was a 33Mhz 80486 processor. The software developed for this demonstration gives the user complete control of the parameters which can be changed from the keyboard at any time.

The testbed operates in two modes, tracking and positioning. It was considered necessary to operate at 200 Hz for positioning mode and 400 Hz for tracking mode. For this it was necessary that the operating system support a mode change from 400 Hz to 200 Hz. Such mode change operation was incorporated in the implementation and successfully demonstrated.

## **Concluding Remarks**

The goal of this effort was to demonstrate the feasibility of using the MARUTI operating system for implementing the control algorithms executing at high frequencies while supporting the control functions desired by the operator. This goal was accomplished successfully.